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The effect of the covariance factor on the Procurement Problem Variance of net leadtime demand

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THE EFFECT OF THE COVARIANCE FACTOR ON THE PROCUREMENT PROBLEM VARIANCE OF NET LEADTIME DEMAND

by

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Thesis Advisor: Alan W. McMasters

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The Effect of the Covariance Factor on the Procurement Problem Variance of Net Leadtime Demand

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TABLE OF ABBREVIATIONS

Variables

Z	- Procurement Problem Variable (PPV)
z	- procurement problem random variable
V	- Procurement Problem Variance
D	- mean demand per quarter
d	- quarterly demand random variable
Var(d)	- variance of quarterly demand
L	- mean procurement leadtime
l	- procurement leadtime random variable
L_2	- net acquisition time
Var(l)	- variance of leadtime
B	- mean regenerations per quarter (CR)(SR)
b	- quarterly regeneration random variable
T	- mean procurement problem turn around time (or mean repair cycle time)
t	- repair cycle time random variable
Var(t)	- variance of repair cycle time

Abbreviations

A/O	- Application/Operation
ASO	- Aviation Supply Office, Philadelphia, PA
COG	- Cognizant Activity
DEN	- Data Element Number
ICP	- Inventory Control Point
ICPDAT	- Inventory Control Point Data
IHF	- Inventory History File
FMSO	- Fleet Material Support Office, Mechanicsburg, PA
MAD	- Mean Absolute Deviation
NICN	- Navy Identification Code Number
NIIN	- National Item Identification Number
NPS	- Naval Postgraduate School, Monterey, CA
NSF	- Navy Stock Fund
OPTION	- Option path formula for variance calculations at ICPs
PVAR	- Mathematically correct formula for variance calculation
SAS	- Statistical Analysis System
SIG	- Selective Item Generator
SPCC	- Ships Parts Control Center, Mechanicsburg, PA
UICP	- Uniform Inventory Control Point

I. INTRODUCTION

A. BACKGROUND

In the U.S. Navy there are approximately 228,800 items classified as repairables. The responsibility for managing these items is shared between the Navy's two inventory control points (ICPs), the Aviation Supply Office (ASO) in Philadelphia, PA., and Ships Parts Control Center (SPCC) in Mechanicsburg, PA. The total dollar value of these items is in excess of $28 billion with an annual Navy Stock Fund (NSF) budget for procurement of just under $2 billion [Ref 1]. To manage the inventories of these high dollar value items, the ICPs use a complex mathematical model which incorporates formulae for the calculation of means and variances of attrition demand over a net leadtime of procurement for specific items.

The mean net leadtime demand calculated is called the Procurement Problem Variable (Z) and the variance of that demand is called the Procurement Problem Variance (V). These two parameters are key elements in determining the procurement quantity that is necessary to maintain a repairable item inventory at prescribed protection levels. Specifically, the mean is the quantity that should be available to meet the average demand over the net leadtime. Additionally, a percentage of the square root of the variance (standard deviation) could be purchased to meet any additional demand that may be experienced. This is essentially a safety level [Ref 2]. The sum of the mean and safety level is the procurement reorder point used by the ICPs.

If, in the calculation of the variance, an error is made resulting in too large a value, more safety stock than necessary may be held. This would tie up money in unnecessary stock and prevent it from being used elsewhere. If the variance calculation was too small, not enough material would be available, resulting in the chance of a "stock-out" being higher than desired.

In the late seventies, the ICPs recognized that the variance model being used, generally calculated variance values that were too high. Two attempts to correct this situation were then incorporated into the model. One was a result of a study completed by Fleet Material Support Office (FMSO) in 1977 [Ref 3]. This study hypothesized that the large variances were a result of ignoring a dependent relationship between the quarterly demand for an item and the quarterly regeneration of carcasses that were returned for repair. The dependent relationship manifests itself as a covariance between these two random variables. This was ignored in the original model when calculating the variance of the net leadtime demand. As a result of this study, an estimate of the covariance between regeneration and demand rates was incorporated into the computerized Levels program (UICP A/O D01) by the ICPs. This estimate was provided as an option path in the Levels program [Ref 4].

The second attempt to reduce variance was done by SPCC in a study completed in the same year [Ref 5]. To prevent excessively large safety levels from being created, a "patch" was added to the Levels program which performs a variance to mean ratio check for each item. If this ratio exceeds an ICP selected parameter, it modifies the program to recompute the variances of the net leadtime demand using a power rule formula [Ref 6].

The variance to mean ratio check, the power rule formula and the estimate of covariance are included in D01, but the use of the covariance term is only an option. This option path is currently not being used at SPCC [Ref 7]. The only definitive reason for not using it was that the ICPs felt that the variance values that were obtained did not provide sufficient safety stock (i.e., too small a variance). Thus, the large variances (that are not recalculated by the power rule because they do not exceed the ICP parameter) which precipitated the initial studies, appear to remain on file at SPCC.

This thesis will look at possible reasons for the large variances mentioned above and will attempt to offer a method for estimating the value of the variances more accurately.

B. OBJECTIVES

There are two main objectives of this thesis. The first is to develop a theoretically correct variance formula for the net leadtime demand which will use the expected values of demand and regeneration rates to calculate the covariance. The second is to compare the theoretically correct formula with the actual variance values on file from SPCC's data base and the option path variance formula of D01. By the comparison with the latter, the degree to which the estimate of the covariance agrees with the theoretically correct formula for covariance can also be obtained.

C. SCOPE

The comparisons made to satisfy the second objective were limited to using a 5% sample of items resident on SPCC's files. No ASO data was examined. No attempt was made to actually calculate safety level or determine actual changes in costs of stock which would result from different variance calculations. However, it follows that any reduction in variance, with all other factors remaining constant, would reduce the amount of safety stock required to provide a given level of protection.

D. PREVIEW

In Chapter II, the two alternatives to be used in this thesis for computing the procurement problem variance will be presented. In particular, the theoretically correct variance formula will be derived and the difference between it and the option path formula will be discussed. Chapter III contains a short discussion on how the data was acquired and the procedures used in the comparison of the three alternatives. In Chapter IV, the results of the comparisons are shown and discussed. Chapter V summarizes the previous chapters, presents conclusions from the analysis, and makes recommendations for further testing and implementation.

II. FORMULA DEVELOPMENT

This chapter begins with a notational caveat and then discusses the concept of the procurement problem variable as the mean demand for an item over a net leadtime. It continues with an explanation of the variance formula used by the ICPs which includes the covariance estimate and variance to mean ratio check that is used to reduce the variance values. The fourth section presents the derivation of a theoretically correct variance formula which will be called "PVAR". The chapter concludes with comparisons of the correct formula with the formulae that are currently being used at SPCC.

A. NOTATIONAL CAVEAT

Capital letters are used to denote the mean values of the variables that they represent. Occassionally, there will be a need to distinguish between these mean values and the distributed random variable from whence they came. This will be accomplished by adopting the expediancy of using the lower case version of the symbol to represent the random variable. All time is measured in quarters.

B. PROCUREMENT PROBLEM VARIABLE

The Procurement Problem Variable (known as PPV and denoted by Z) is the expected demand over an "average acquisition time". The term "variable", in this case, is a misnomer. It is a mean of the distribution of the procurement problem random variable, not a random variable itself. However, the term has been accepted by convention, to represent the expected demand over a net leadtime.

To develop this net leadtime, let B represent the average number of items regenerated per quarter and let D be the average number of items demanded per quarter. The ratio of B/D then represents the average proportion of demands that are satisfied by regenerations and 1 - B/D is the average proportion of demands that are not, and thus have to be procured. Next, let L represent the mean procurement leadtime and T represent the mean repair turn-around time.

The average of the net acquisition time, L_2, can then be represented by the following formula:

$$(1) \qquad L_2 = (1 - B/D)L + (B/D)T.$$

Multiplying this formula by the average quarterly demand, D, will produce the average demand over L_2.

$$(2) \qquad DL_2 = DL - BL + BT = Z.$$

Equation (2) is the formula used by the ICPs for computing Z, the mean of the net leadtime demand [Ref 4].

C. UICP VARIANCE FORMULA

The variance formula that was used in the middle 1970's was:

$$(3) \qquad V = (L - T)[Var(d) + Var(b)] + TVar(d) + D^2Var(t) + (D - B)^2[Var(l) + Var(t)].$$

The above equation was pieced together from a Fleet Material Support Office (FMSO) Working Memorandum [Ref 3] and the current computerized Levels program documentation (UICP A/O D01) [Ref 4]. The memorandum, which was a summary of a study completed in 1977, suggested changes to the above equation (3) that would reduce the variance of net leadtime demand of repairables. The problem of observed large variances at the Inventory Control Points (ICP) in the mid seventies was important to them because of increasing funding restrictions and budgetary limitations that were being imposed upon the supply system at that time. They recognized that a reduction in variance values would reduce the amount of money needed to fund safety stock. To accomplish this reduction, the ICPs incorporated the changes that were recommended by the study.

The major change that was incorporated was an estimate of the covariance between the demand rate and regeneration rate of a repairable item. From the FMSO study the estimate had the form of:

(4) $\quad \mathrm{Var}(d)B/D$

The ICPs programmed the above covariance estimate into the variance equation as an option path. The option path has the following form:

(5) $$\mathrm{OPTION} = (L - T)[\mathrm{Var}(d) + \mathrm{Var}(b) - 2\mathrm{Var}(d)B/D] + T\mathrm{Var}(d) + D^2\mathrm{Var}(t) + (D - B)^2[\mathrm{Var}(l) + \mathrm{Var}(t)].$$

The above equation (5) is the same formula that is documented in the current Levels program. However, the option path, according to SPCC's Operations Analysis Division [Ref 7], is not being used. The only variance reduction technique that is currently being used is a variance to mean ratio check and subsequent power rule recalculation of variance.

The variance to mean ratio check and the power rule were implemented as a result of a study completed by SPCC in 1977 [Ref 5] which was also motivated by the excessively large variances of net leadtime demand that were on file. To prevent large safety levels from occurring, a "patch" was added to the Levels program which compared the variance of net leadtime demand, calculated from equation (3), with the mean of net leadtime demand, calculated from equation (2). If this ratio exceeded a preset ICP parameter (SPCC = 150, ASO = 450), the variance calculated by equation (3) was recalculated using the following formula (power rule):

(6) $\quad V = a(Z)^b,$

where a and b are preset parameters.

The above parameters (a,b) are currently set at SPCC as 4.849 and 1.502, respectively, and at ASO as 27.458 and 1.559, respectively [Ref 10]. These parameters are reviewed approximately every three years by FMSO.

In summary, the current variance calculations at the ICPs are obtained by using equation (3) and the variance to mean ratio check with the power rule. The actual variance values on file at SPCC will be referred to as "V" throughout the rest of this paper. Note that even though equation (3) and equation (5) are calculations for the variance of net leadtime demand, V, to prevent confusion, the results of equation (5) will be referred to as "OPTION". OPTION, equation (5), is only programmed as an option path and, as previously mentioned, is not being used.

D. PVAR FORMULA

The procurement problem variable, as shown in formula (2) can be derived in another way as follows. Let l be the number of quarters required for procurement of a new item. Let t be the repair turn-around time necessary to repair a carcass of the same item. The mean net number of items to buy to meet demand over l can be described by the regression function [Ref 9] as follows:

$$(8) \qquad E[z \mid l,t] = lD - (l-t)B$$

This equation has the following interpretation. The first term, $lD = lE[d]$, is the expected number of items demanded given the procurement leadtime, l. This value must be offset by the mean number of carcasses expected to be returned to inventory in "ready for issue" condition (RFI) over l. For the first t periods of the given l periods a number of carcasses are being repaired. The number of such carcasses is the consequence of the number of items returned to supply for repair prior to our time origin. After t such items can be used to fill demands. The term $(l - t)B = (l-t)E(b)$ represent a conditional expectation of those regenerations after our time origin. This is the reason for the negative term in (8). Using the basic rule of iterated expectations,

(9) $E[z] = E[E[z \mid l,t]]$.

It then follows:

(10) $Z = LD - (L - T)B,$

which can be rewritten to show that it is identical to formula (2):

$$Z = DL - BL + BT.$$

To develop the variance of net leadtime demand, the regression function (8) can be used. Rewriting the regression function of net demand (z) on leadtime (l) and repair cycle time (t) provides the following:

(11) $E[z \mid l,t] = (l - t)(D - B) + tD,$

and the conditional variance of z given l and t is:

(12) $Var(z \mid l,t) = (l - t)Var(d - b) + tVar(d),$

because we are summing (l - t) independent observations of (d - b) and adding it back to independent observations of d.

Using the Lemma stated and proved by FMSO [Ref 10] (i.e., the unconditional variance is the mean of the conditional variance plus the variance of the regression function) results in:

(13) $$\begin{aligned} Var(z) &= (L - T)Var(d - b) + TVar(d) + Var(l(D - B) + tB), \\ &= (L - T)Var(d - b) + TVar(d) + (D - B)^2Var(l) + B^2Var(t), \end{aligned}$$

because procurement leadtime and repair cycle time are independent variables.

Since current repairables inventory management procedures [Ref 11] require a return of a carcass concurrently with a requisition for another unit of the repairable (i.e., a one for one exchange), this creates a dependent relationship between the number of carcasses returned to supply for repair and the demand for the same item. Accounting for this dependent relationship, twice the covariance between demand and regeneration (because each is dependent on the other) is subtracted from [Var(d) + Var(b)]. The following formula results:

$$(14)\qquad \mathrm{Var}(z) = (L - T)[\mathrm{Var}(d) + \mathrm{Var}(b) - 2\mathrm{Cov}(d,b)] + T\mathrm{Var}(d) + B^2\mathrm{Var}(t) + [(D - B)^2\mathrm{Var}(l)].$$

The covariance term from the above equation (14) can be derived using expectations [Ref 14]:

$$(15)\qquad \mathrm{Cov}(d,b) = E[(d - D)(b - B)], \quad = E[db] - DB.$$

When (15) is inserted in (14) the resulting equation, which will be called PVAR, for calculating the variance of demand over a net acquisition leadtime is:

$$(16)\qquad \mathrm{PVAR} = (L - T)[\mathrm{Var}(d) + \mathrm{Var}(b) - 2(E[db] - DB)] + T\mathrm{Var}(d) + B^2\mathrm{Var}(t) + [(D - B)^2\mathrm{Var}(l)].$$

E. FORMULA COMPARISONS

If PVAR, equation (16), is subtracted from V, equation (3), the difference is:

$$(17)\qquad V - \mathrm{PVAR} = 2D\mathrm{Var}(t)(D-B) + (L - T)2\mathrm{Cov}(d,b).$$

Adding PVAR to both sides and expanding terms results in an expression relating V and PVAR:

$$(18)\qquad V = \mathrm{PVAR} + (D^2 - B^2)\mathrm{Var}(t) + (D - B)^2\mathrm{Var}(t) + (L - T)2\mathrm{Cov}(d,b).$$

Collecting terms and simplifying:

$$(19)\qquad V = \mathrm{PVAR} + 2D\mathrm{Var}(t)(D-B) + (L - T)2\mathrm{Cov}(d,b).$$

It is interesting to note when PVAR would equal V. If we assume that $L > T$, then $V = PVAR$ when the following is true:

$$(20) \qquad DVar(t)(D - B) = -(L - T)Cov(d,b).$$

A special case of the above would occur when both terms are zero. That results from any one term (on both sides) being zero. This is not an uncommon event (i.e., Cov(d,b) and Var(t) equal to zero) as will be shown in the following chapters. Also note that if the covariance term was negative (i.e., $E[db] > DB$) and any term on the left side of equation (20) was zero (i.e., $Var(t) = 0$), then PVAR would be greater than V. Mathematically it is possible for the covariance term to be negative, but conceptually it is not since a probability of a regeneration will exists when a demand occurs and the regeneration rate can never be negative. The negative covariance term is not an uncommon event when working with the data and may suggest problems with the data on file. This investigation is left for further study.

The same procedures as above can be used to compare PVAR and OPTION. For simplicity, let the estimate of covariance, equation (4), be represented by Cov' and let the calculation of covariance, equation (15) be represented by Cov. This comparison results in:

$$(20) \qquad OPTION = PVAR - 2[Cov'(d,b) - Cov(d,b)] + (D^2 - B^2)Var(t) + (D - B)^2Var(t).$$

As discussed above, if $Var(t) = 0$, then the difference between OPTION and PVAR reduces to:

$$(21) \qquad OPTION = PVAR -2[Cov'(d,b) - Cov(d,b)].$$

Then PVAR and OPTION will be equal when:

(22) $\quad Cov'(d,b) = Cov(d,b),$

and PVAR will be less than OPTION when:

(23) $\quad Cov'(d,b) > Cov(d,b).$

This last situation, equation (23), will be discussed in depth in Chapter IV.

III. FORMULA COMPARISON METHODOLOGY

This chapter begins with an explanation of how the data was obtained from the files of SPCC and loaded to the Naval Postgraduate School's (NPS) mainframe computer. It then explains the process used to compare the variance, V, on file at SPCC, with the option path formula for variance, OPTION, and the theoretically correct variance formula, PVAR.

A. DATA ACQUISITION

The data used to compare the three models was taken from SPCC's data files on the Univac 494 computer. The data consisted of all repairable items with a cognizant activity code (COG) of 7H, 7I, and 7G. These COGs indicate that the items are specically managed by SPCC. The data elements necessary to calculate the variances were downloaded to tape via the ICPDAT (inventory control point data) network using the computer resources of the Operations Research Department (Code 93) at FMSO. The specific Data Element Number (DEN) and nomenclature of each data element are presented in Appendix A. It was necessary to access two different files to obtain all the data elements. The SIG (selective item generator) file was used for most of the data and the IHF (inventory history file) was accessed for specific data necessary to calculate expected values (for Cov(d,b)). Once the data was acquired, it was translated into IBM format for storage in National Item Identification Number (NIIN) sequence on the new IBM 3090 mainframe at SPCC. A mainframe data analysis package, SAS, was used to eliminate any NIIN which had blanks or data missing from any DEN. An example would be a NIIN that had data on the SIG file but no IHF entries and vice versa. For the purpose of this data selection, zero was considered a valid data entry, but blanks were not. Finally, a tape was obtained of the remaining data. This tape was taken to the Naval Postgraduate School (NPS) where it was uploaded on the IBM 370/3033AP mainframe and stored in a batch data file. Due to the size of the data (in excess of 47,000 line items or

NIINs), a 5% sample was taken from the batched data set and loaded to a private disk (B-disk). The private disk allowed interactive programming, which was not available if kept on the batch file. The 5% size was the largest sample size that could be loaded and stored on a private disk (1672K bytes of disk space). The resulting sample had a total sample size of 2,345 observations. Each observation consisted of a NIIN and all data elements pertaining to that NIIN that were needed for computing the variances being compared.

Since the batch file was arranged in NIIN sequence, the sequential sampling technique [Ref 12] was used to ensure a continuous, representative sample across all NIINs. To obtain the 5% sample, the data was sequentially subdivided into blocks of 20 items. A number between 1 and 20 was selected at random to determine which item from each block would be sampled. The 5% sample, therefore, consisted of one item from each block.

B. FORMULA COMPARISON PROCEDURES

The V, PVAR and OPTION formulae were programmed on the NPS mainframe computer using FORTRAN. The actual code is presented in Appendix B. The resulting variances from each of these equations were compared to the corresponding variance obtained directly off SPCC's file, V1. The file variance value is denoted by V1 to distinguish it from the programmed UICP variance formula, V. V1 was used as the comparison value because it is the actual variance used in the calculation of inventory levels. V was used only to compare it to V1 to see if the variance on file could be duplicated by a simple formula. If V1 could not be duplicated then some method other than direct calculation of the variance was used by SPCC. It is assumed that the power rules were used to estimate the variances of the components within the variance formula. A recent study by FMSO [Ref 8] indicates that the mean absolute deviations (MAD) that are used to compute the variances of several of the variables in the calculation of the variance are estimated by power rules similar to the one discussed above. The affect of the power rules and the resulting variance values is left to further study.

As discussed under SCOPE, no direct comparison of OPTION and PVAR will be done with V. Thus, the comparison of variance values will be done between V1 (the values on file at SPCC) and V (the UICP variance formula), and between V1 and OPTION (the UICP option formula for calculating variance) and PVAR (the theoretically correct variance formula).

A series of data checks were built into the program to remove any item with data that resulted in calculations of a negative Z, a leadtime demand of zero or less or D (mean quarterly demands) that were equal to zero. The last check was done to prevent division by zero when using the OPTION equation.

The values of the three variances were tabulated in a series of output files. The output files were then divided into specific categories of demand for several reasons. It was important to reduce the size of the comparison groups to make data analysis easier in GRAFSTAT. When the data set is too large, the graphic output exceeds its capacity. Another reason is that the ICPs use certain mean quarterly demand values as a criteria for determining underlying probability distributions for demand during net leadtime. It was also considered important to separate the high demand items from the lower demand items since they are managed more intensely. A series of demand groupings were therefore defined. Costs associated with a stock-out are higher if the safety levels for these high demand items are inaccurate.

The "Low Low Demand" items had mean quarterly demands of less than one unit. The "Medium Low Demand" items had mean quarterly demands equal to or greater than 1 but less than 2 units. Items with mean demands equal to or greater than 2 but less than 5 were grouped into the "High Low Demand" category. The "Medium Demand" category contained items with mean demands equal to or greater than 5 but less than 20 and the "High Demand" items were those with mean quarterly demands of 20 units or more.

In addition to V1, PVAR, OPTION, and V, the output files contained an identification number for a specific NIIN (I), the PPV (Z) value and various other data elements. Finally, the standard deviation or square root of each variance (except V because this was not in the comparison) and the ratio (V/Z) were included. This ratio was used to look at how many of the samples exceeded the variance to mean ratio parameter at SPCC of 150.

The output files were input to an NPS mainframe statistical analysis package, GRAFSTAT, for graphical analysis. The output from this package did not integrate well into a microcomputer word processor and thus was used only to find trends between the variance calculations. Once trends were observed, the original FORTRAN program was modified to produce summary data of the results. These results were then fed into a microcomputer. Using the microcomputer and Harvard Graphics, graphs of the summary data were then prepared and imported to WordPerfect 5.0 for use in this thesis.

C. DATA FILE OUTPUT

A total of 1,261 items (53.8%) passed through all the data checks. A cursory look at the items not passing the check showed that most of the items had mean demands that were less than one per quarter and many of the data elements had zero values. A large majority of these items were identified as new items because they were coded with Navy Item Code Numbers (temporary NICN's appeared instead of NIIN's) for which little or no historical data was available. Most of these items should have been screened from the data set during initial download at SPCC, but were not because of the presence of zeros in the data fields instead of blanks. It could not be determined why the zeros were entered in the DENs. However, zeros allowed them to pass through the initial screening but then caused them to fail the final data checks built into the calculation programs. In addition, some of these items were identified as having gone through a Cognizant Activity change (i.e., COG migration) which is a change of activity responsible for the supply management of the particular item or reclassification from an item having been identified by a NICN to an item which is now identified by a NIIN. This would cause a "disconnect" between data on the IHF (Inventory History File) which was associated with a NICN and the same item on the SIG (Selective Item Generator) File which is now identified by a NIIN. This normally would have produced blanks and would have been screened out initially but the presence of unexplainable zeros prevented it.

IV. RESULTS

The data was run through the different variance calculations and the results were divided into demand groups as mentioned in Chapter III. Figure 1 shows the distribution of the items among the different demand groups.

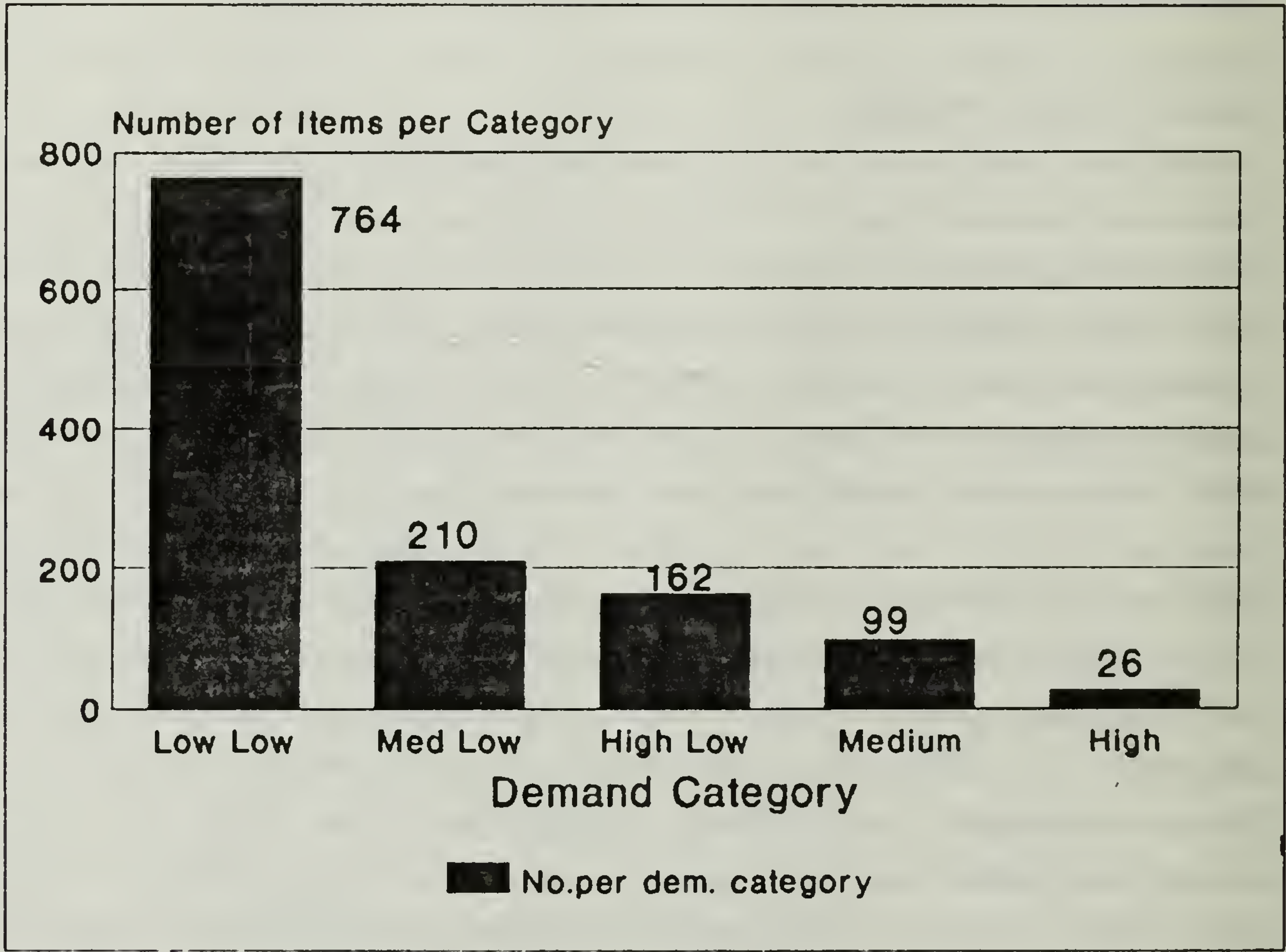

Figure 1 - Distribution of the 1261 items by quarterly demand category.

A sample of the detailed output file for high demand items are presented in Appendix C.

As can be seen from Figure 1, most of the items were in the low low demand group. Those items that the ICP consider for intense management are in the medium and high demand group. Even though they are only a small percent of the total items in the sample, they reflect the relative percentages for the entire population.

Figure 2 shows the percentage of items in each demand category that had a reduction in variance values (over V) as a result of the PVAR calculations and OPTION calculations.

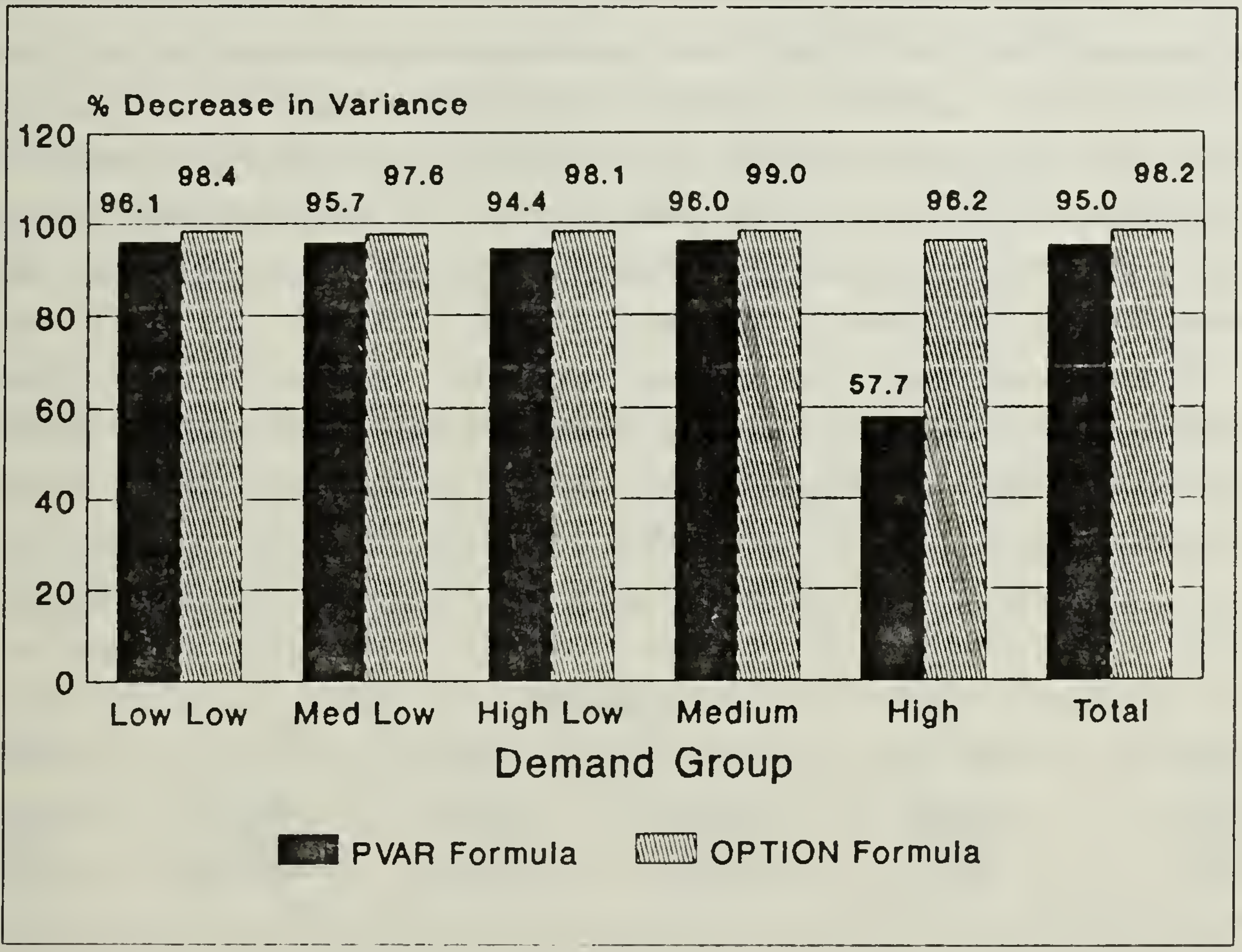

Figure 2 - Percent of items within each demand group that showed a reduction of variance values by PVAR and OPTION.

Note that in every demand category, the OPTION formula reduced the variance by a larger percentage than did the PVAR formula. The main reason for this is that a large number of items, when using the PVAR formula, had demand-regeneration covariances equal to zero. This was caused by regeneration data equal to zero. This did not occur when using the OPTION formula because it used the mean regeneration value that was on file while PVAR used the raw data to calculate mean regeneration. This suggests that mean regeneration values are being calculated at SPCC by some other method and not from data on file. The investigation of this point is left for further study.

As can be seen in Figure 2, for the high demand items, PVAR reduced the variance for only 57.7% of the items. This was the lowest improvement shown by PVAR. Those items that did not have their variances reduced, fell into two categories. They were either items that had covariances equal to zero (in the PVAR formula) because of regeneration data equal to zero or the variance to mean ratios (as shown by V/Z) were greater than the variance to mean ratio check parameter of 150. In the latter case, V1 was computed using the power rule while PVAR was calculated as programmed (the use of the power rule in calculating V1 was verified by hand).

Table I shows typical items in these categories. Item number 313 had a zero covariance when PVAR was used to calculate variance. Item number 1287 had V1 recomputed using the power rule. Finally, item number 560 fell into both categories.

TABLE I

ITEM	Z	V1	PVAR	V	ratio
313	96.75	2671.48	5747.1	5747.1	59.40
1287	93.43	4422.21	15911.4	15922.9	170.43
560	99.08	4824.57	15793.5	15793.5	159.40

A small quantity of the items (7 items with high demand and 14 total) from the output file had variance to mean ratios greater than 150 (V/Z > 150). Of these 14 items 4 had PVAR values that would not have passed the variance to mean ratio check. This suggests, in this particular case, the cut-off parameter of 150 may be too severe. If this situation is true then not enough safety stock is being held to meet the required protection level.

For the rest of the demand categories, Figure 2 shows that PVAR is only slightly less effective than OPTION, in reducing the variances of the sample. The main reason given that SPCC has not used the OPTION formula is that it calculates variances which have been shown to be too small to provide sufficient safety stock. If PVAR were implemented, then quite possibly the same would hold true. However, the discussions so far have been limited to the number of items for which variances were reduced, not the degree of reduction. To determine the degree of reduction, the differences in standard deviations (square root of the variances) were plotted for all items where V1 (the variance on file) was less than PVAR and PVAR was less than OPTION. From the plots, summary data was gathered and is shown in histogram form in Figure 3. This figure accounts for 94% of the items sampled. The other 6% of the sample that is not included are items where the PVAR formula calculated a zero covariance or where the variance to mean ratio exceeded 150. These items were discussed above.

In Figure 3 the data is grouped by the difference in number of items. Option shows a decrease in standard deviation over PVAR by a median value of 3. PVAR shows a decrease in standard deviation over V1 by a median value of 1. From the difference between V1 and PVAR it appears that for the same level of protection, "on the average", less safety stock would be required if the PVAR formula was used. From the differences between OPTION and PVAR, the OPTION formula, "on the average", provides even less safety stock than PVAR.

According to SPCC, the OPTION formula is not used because it reduces the variance of net leadtime demand too much and thus does not provide enough safety stock. On the other hand the variances on file (V1) are apparently too large and have been the object of a number of studies and program modifications to reduce their values. The PVAR formula, as presented in this thesis, reduces the variance, as compared to V1. However, PVAR does not reduce it to the level of OPTION. Thus, PVAR might be the solution to this dilemma.

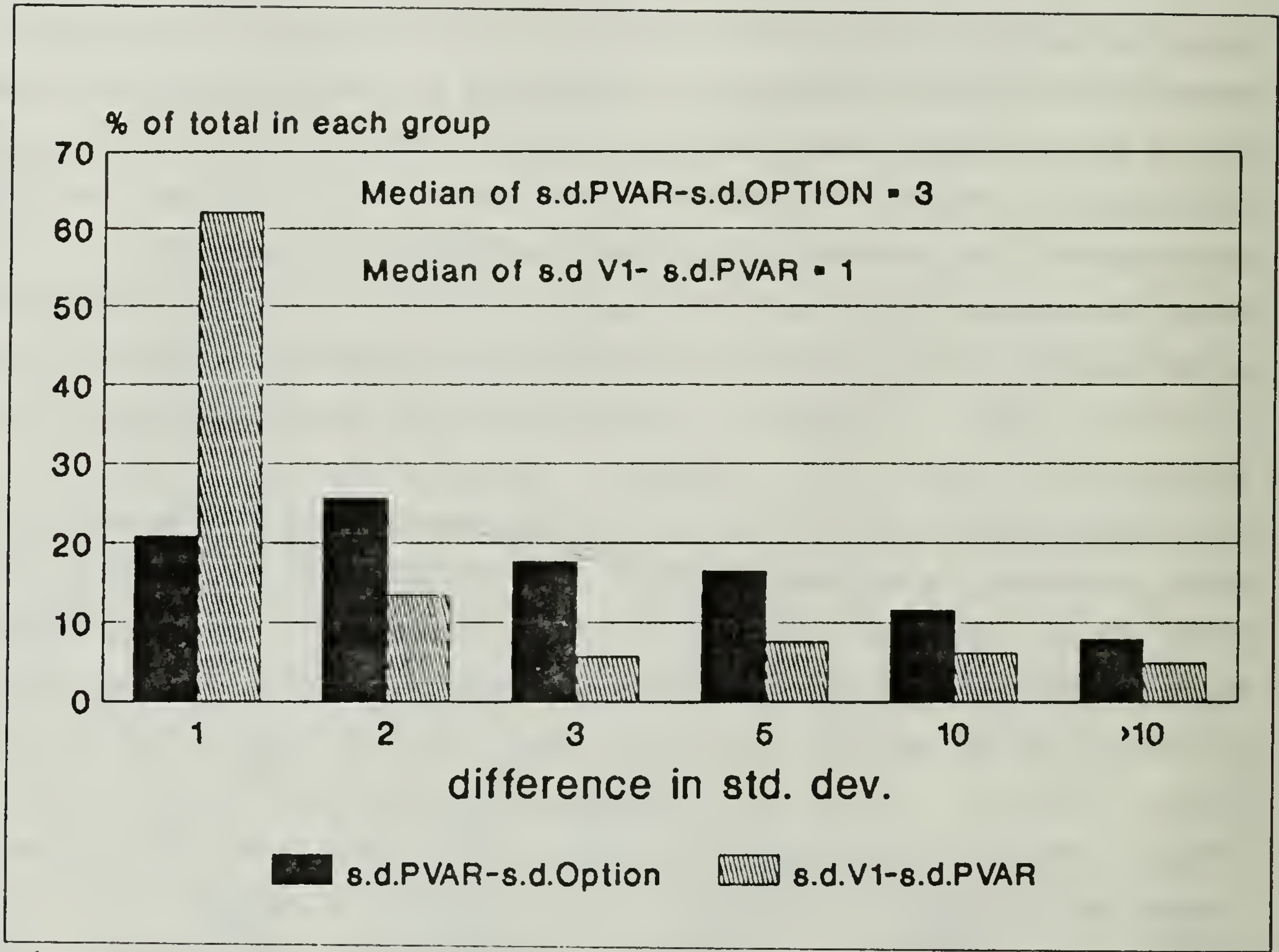

Figure 3 - Difference in standard deviations between variance formulae.

V. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This thesis has compared different formulae that are or could be used to calculate the variances of the net leadtime demand for SPCC managed repairable items. PVAR, the theoretically correct variance formula, was derived directly calculate the covariance between quarterly demands and quarterly regenerations. The differences between the OPTION formula (documented in UICP A/O D01), the PVAR formula (derived in Chapter II), and the variance formula used to compute the current values listed on SPCC's data files were discussed. The variance values listed on SPCC's data files were then compared with the variance values calculated by both the OPTION formula and the PVAR formula. Finally, an analysis of the results from the comparisons of the different variance formula was presented.

B. CONCLUSIONS

It is a well known fact that a large variance in net leadtime demand resident on SPCC's file can result in unusually large safety stock. In the past, various changes to the UICP programs have been implemented which reduce the variance to acceptable levels to prevent large sums of money from being tied up in possibly unused and unnecessary safety stock. The current procedure is to make a variance to mean ratio check and to recalculate the variance of net leadtime demand if it exceeds a predetermined threshold. An alternative available estimates the covariance factor and uses the option path for computing the variance. This approach was designed to reduce the variance to acceptable levels by accounting for covariance between the dependent variables of demand and regeneration. The option path, if it were used, apparently underestimates the variance of net leadtime demand and would excessively reduce the amount of safety stock required. While this would reduce, considerably, the amount of dollars necessary to procure and maintain the safety level, it could also reduce the levels of operational availability of various weapon systems by not providing enough safety stock.

The PVAR model, when used with complete and current data, reduces the variance of over 95% of the repairable items sampled. It also does not estimate the covariance of regeneration and demand, but calculates it directly and thus gives a more theoretically correct variance output. In addition, it does not reduce the variances to the levels calculated by the OPTION formula. By using the PVAR model, SPCC could reduce the amount of money tied up in unnecessary safety stock for those items which had large variances on file and redistribute some of the money to items which may require, for what ever reason, an increase in protection level (i.e., more safety stock). This would possibly allow an increase in operational availability of weapon systems and at the same time could reduce the amount of money necessary for spares support. It would allow the ICP to do its job cheaper and smarter.

C. RECOMMENDATIONS

The results indicated here, should not imply that the PVAR model is a panacea for a restrictive funding environment. The model should be thoroughly tested and verified through simulation and under actual operating conditions prior to any consideration being given to incorporating it into levels setting.

In particular, PVAR should continue to be tested using data obtained from ASO to see if similar results (as obtained in this study) apply to aviation material. In addition, simulation and actual field testing of PVAR should be done to see if the variance values that are calculated by PVAR provide for enough safety stock.

FMSO has recently completed a new Functional Description (PD-80) [Ref 13] for a UICP program system design to forecast leadtime and repair turn-around time. The documentation and program are to be incorporated into the software modifications being made as part of the ICP modernization project. The procedures described in PD-80 include many significant improvements over D01, but the basic formula for calculating the variance of demand over net leadtime is still similar to equation (5) in Chapter II. When the PVAR model passes testing, corrections can easily be made to PD-80 and then implemented without delay. By correcting only the variance formula, and maintaining the other significant improvements of PD-80, the ICPs would not only operate more economically but also provide the necessary spares support for the fleet.

D. RELATED FURTHER STUDY

Further study should be directed toward the policy governing the use of the power rules for estimating the mean absolute deviation of the components of the variance formula. If the reason for estimating these MADs is due to lack of data, then this lack of data needs to be investigated as well. Blank data fields were screened out of this study. These blanks will affect the new Levels program (PD-80) that does not use MADs but instead calculates directly the variances of the individual components of the formula for variance of net leadtime demand.

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APPENDIX A

DEN/Nomenclature of Data Elements

A019	- Observed Quarterly Demand MAD
B011B	- Procurement Leadtime MAD
A019B	- Observed Quarterly Carcass Return MAD
B011A	- Procurement Leadtime Forecast
B012F	- Average Procurement Turn-Around Time for repair
B012B	- Average Carcass Return Rate
B019A	- Variance on File at SPCC
B023C	- Demand over Procurement Leadtime
B023E	- Regenerations over Procurement Leadtime
B023G	- Regenerations during repair turn-around time
B074	- Average Quarterly System Demand Forecast
B032C	- Observed Leadtime Demand
B074A	- Quarterly RFI Regenerations
C001E/C002	- National Item Identification Number
C003	- Cognizant Activity
C005	- Unit of Issue
F020 - F020G	- Depot completions reported for the last 8 quarters
F009	- Repair Survival Rate
F009A	- Repair Survival Rate MAD
H014,H014A,H014C - H021,H021A,H021C	- Total quarterly demand reported for the last 8 quarters

APPENDIX B

FORTRAN PROGRAM FOR VARIANCE CALCULATION

```
*******************************************************************************
*THIS PROGRAM READS THE DATA FROM THE DATA FILE "SIGIHF" AND PUTS IT          *
*IN COLUMN VECTORS FOR FURTHER ANALYSIS.  THE DATA SET IS IN CHARACTER        *
*FORMAT WITH A LRCL = 236. THE OUTPUT IS "RATIODAT LISTING A"                 *
*COMPILE THE PROGRAM USING FORTVS AND USE THESIS EXEC TO RUN                  *
*THE VARIABLES ARE:                                                           *
*  CNIIN - NATIONAL ITEM IDENTIFICATION NUMBER (C001E/C002)                   *
*  COG - COGNIZANT ACTIVITY (C003)                                            *
*  DEMMAD - OBSERVED DEMAND MAD (A019)                                        *
*  PLTMAD - PROCUREMENT LEADTIME MAD (B011B)                                  *
*  PLTFC - PROCUREMENT LEADTIME FORCAST (B011A)                               *
*  DEM - AVERAGE QUARTERLY SYSTEM DEMAND FORCAST (B074)                       *
*  LTDEM - OBSERVED LEADTIME DEMAND (B023C)                                   *
*  RATIO1 - VARIANCE TO MEAN RATIO FROM FILE (V1/PPV)                         *
*  RATIO2 - NEW VARIANCE TO MEAN RATIO CALCULATED (PVAR/PPV)                  *
*  RATIO3 - VARIANCE TO MEAN RATIO CALC FROM (OPTION/PPV)                     *
*  RATIO4 - VARIANCE TO MEAN RATIO WITHOUT COVARIANCE D01 (V/PPV)             *
*  RATDIF - DIFFERENCE BETWEEN CALCULATED VAR/MEAN AND FILE VAR/MEAN          *
*  CRMAD - OBSERVED CARCASS RETURN MAD (A019B)                                *
*  PTAT - AVERAGE PROCUREMENT TURN-AROUND TIME FOR REPAIR (B012F)             *
*  NTTMAD - NAVY (NON-REPROTING) REPAIR TURN-AROUND TIME (B012B)              *
*  AVGCR - AVERAGE CARCASS RETURN RATE (B022B)                                *
*  LREGEN - RFI REGENERATIONS DURING LEADTIME (B023E)                         *
*  TREGEN - RFI REGENERATIONS DURING PTAT (B023G)                             *
*  QREGEN - QUARTERLY RFI REGENERATIONS (B074A)                               *
*  RSRMAD - REPAIR SURVIVAL RATE MAD (F009A)                                  *
*  QTR1RP THRU QTR8RP - DEPOT COMPLETIONS REPORTED FOR THE LAST 8 QTR         *
*                          (F020 THRU F020G)                                  *
*  RSR - REPAIR SURVIVAL RATE (F009)                                          *
*  UI - UNIT OF ISSUE (C005)                                                  *
*  QTR1DM THRU QTR8DM - TOTAL QTRLY DEMAND REPORTED FOR THE LAST 8 QTR        *
*                          (H014+H014A+H014C THRU H021+H021A+H021C)           *
*  OPTION - CALCULATED VARIANCE BY THIS PROGRAM WITH COVARIANCE COV1          *
*  V1 - VARIANCE OF PPV ON SPCC'S FILE(B019A)                                 *
*  V - VARIANCE FROM D01 WITH OUT COVARIANCE                                  *
*  COV1 - EST OF COVARIANCE FACTOR USED AT THE ICPS                           *
*  COV - COVARIANCE FACTOR CALCULATED BY EXPECTED VALUES                      *
*  PPV - PROCUREMENT PROBLEM VARIABLE (B023C-B023E+B023G)                     *
*  PVAR - CALCULATED PROCUREMENT PROBLEM VARIANCE WITH COVARIANCE COV         *
*  BDATA - COUNTER FOR BAD DATA WHICH WILL NOT BE USED IN ANALYSIS            *
*  GDATA - COUNTER FOR GOOD DATA WHICH WILL BE USED IN ANALYSIS               *
*  POSDIF - COUNTER FOR POSITIVE IMPROVEMENT IN VARIANCE WITH PROGRAM         *
*  NEGDIF - COUNTER FOR NEGATIVE IMPROVEMENT IN VARIANCE WITH PROGRAM         *
*  UNCHNG - TOTAL QTY OF NIINS WITH VARIANCE UNCHANGED BY PROGRAM             *
*  VDIF - DIFFERENCE BETWEEN VARIANCE ON FILE AND CALCULATED VARIANCE         *
*  COUNT1-5 - COUNTER FOR VAR EXCEEDING SPCC PARAMETER FOR RATIO              *
*  DELTA - DIFFERENCE IN STANDARD DEVIATION                                   *
*  NUM - NUMBER OF ITEMS USED TO CALCULATE S.D.                               *
*  J - SETS THE NUMBER OF DATA LINES (NIINS) TO BE READ/USED                  *
```

```
*  P - SPCC PRESET PARAMETER                                                   *
*  S - CONSTANT FOR THE ESTIMATION OF VARIANCE FROM THE MAD                    *
*  V1SD -STD DEV OF V1
* PVARSD - STD DEV OF PVAR
* OPSD - STD DEV OF OPTION
* DIFF - DIFFERENCE BETWEEN PVAR AND OPTION S.D.(PVARSD-OPSD)
*******************************************************************************
* DECLARE VARIABLES, SET PARAMETERS, DIMENSION ARRAYS
      PARAMETER (J=2345, S=1.25, P=150)
      REAL PLTFC(J), DEMMAD(J), DEM(J), LTDEM(J), V1(J), CRMAD(J),
     CPTAT(J),NTTMAD(J), AVGCR(J), LREGEN(J), TREGEN(J), QREGEN(J),
     CRSRMAD(J), RSR(J), PVAR(J), COV(J), PPV(J), V(J), RATIO1(J),
     CRATIO2(J), RATIO3(J), VDIF(J), RATDIF(J), COV1(J), RATDEL(J)
     C,RATIO4(J), OPTION(J), DELTA(J), TOTDEL,V1SD(J),PVARSD(J),
     COPSD(J),DIFF(J)
      INTEGER  PLTMAD(J), QTR1RP(J), QTR2RP(J), NEGDIF, POSDIF, NEGDEL
     C, POSDEL, UNDEL, COUNT1, COUNT2, COUNT3, COUNT4, COUNT5,
     CQTR3RP(J), QTR4RP(J), QTR5RP(J), QTR6RP(J), QTR7RP(J), UNCHNG,
     CQTR8RP(J), QTR1DM(J), QTR2DM(J), QTR3DM(J), QTR4DM(J),
     CQTR5DM(J), QTR6DM(J), QTR7DM(J), QTR8DM(J), BDATA, GDATA,
     CPDIF1, PDEL1, NDIF1, NDEL1, PDIF2, NDIF2, PDEL2, NDEL2, PDIF3,
     CNDIF3, PDEL3, NDEL3, PDIF4, NDIF4, PDEL4, NDEL4, PDIF5, NDIF5,
     CPDEL5, NDEL5,NUM,DEL,ONEF,ONEL,TWOF,TWOL,THREEF,THREEL,
     CFIVEF,FIVEL,TENF,TENL,GTENF,GTENL
      CHARACTER*9 CNIIN(J)
      CHARACTER*2 UI(J),COG(J)
      BDATA=0
      GDATA=0
      NEGDIF=0
      POSDIF=0
      PDIF1=0
      NDIF1=0
      PDEL1=0
      NDEL1=0
      PDIF2=0
      NDIF2=0
      PDEL2=0
      NDEL2=0
      PDIF3=0
      NDIF3=0
      PDEL3=0
      NDEL3=0
      PDIF4=0
      NDIF4=0
      PDEL4=0
      NDEL4=0
      PDIF5=0
      NDIF5=0
      PDEL5=0
      NDEL5=0
      COUNT1=0
      COUNT2=0
      COUNT3=0
      COUNT4=0
      COUNT5=0
      TOTDEL=0.0
```

```
      NUM=0
      DEL=0
      ONEF=0
      ONEL=0
      TWOF=0
      TWOL=0
      THREEF=0
      THREEL=0
      FIVEF=0
      FIVEL=0
      TENF=0
      TENL=0
      GTENF=0
      GTENL=0

      WRITE(9,*) '-',' I ','    V1    ','  PVAR   ','  OPTION ',
     C'    V    ','    Z    ','  A SD   ','   V1 SD ',' PVAR SD ',
     C' OPTION SD','   V/Z   '

*  READ DATA FILE AND CREATE DATA VECTORS

      DO 10 I=1, J
           READ (1,15) CNIIN(I), COG(I), DEMMAD(I), PLTMAD(I), PLTFC(I),
     C     DEM(I), LTDEM(I), V1(I), CRMAD(I), PTAT(I), NTTMAD(I),
     C     AVGCR(I), LREGEN(I), TREGEN(I), QREGEN(I), RSRMAD(I),
     C     QTR1RP(I), QTR2RP(I), QTR3RP(I), QTR4RP(I), QTR5RP(I),
     C     QTR6RP(I), QTR7RP(I), QTR8RP(I), RSR(I), UI(I),
     C     QTR1DM(I), QTR2DM(I), QTR3DM(I), QTR4DM(I), QTR5DM(I),
     C     QTR6DM(I), QTR7DM(I), QTR8DM(I)
15         FORMAT (A9, A2, F10.4, I3, 2(F9.2), F10.2, 2(F10.4), F4.2,
     C     F3.1, F10.2, 2(F9.1), F9.2, F3.2, 8(I5), F3.2, A2, 8(I9))

* CALCULATE COV, COV1, V, PPV AND PVAR

          COV(I)= (((QTR1DM(I)*QTR1RP(I))+(QTR2DM(I)*QTR2RP(I))
     C+(QTR3DM(I)*QTR3RP(I))+(QTR4DM(I)*QTR4RP(I))+(QTR5DM(I)
     C*QTR5RP(I))+(QTR6DM(I)*QTR6RP(I))+(QTR7DM(I)*QTR7RP(I))
     C+(QTR8DM(I)*QTR8RP(I)))/8)-(((QTR1DM(I)+QTR2DM(I)+QTR3DM(I)
     C+QTR4DM(I)+QTR5DM(I)+QTR6DM(I)+QTR7DM(I)+QTR8DM(I))/8)
     C*((QTR1RP(I)+QTR2RP(I)+QTR3RP(I)+QTR4RP(I)+QTR5RP(I)+
     CQTR6RP(I)+QTR7RP(I)+QTR8RP(I))/8))

      IF(DEM(I).LE.0) THEN
          BDATA=BDATA + 1
          GOTO 10
      END IF

         COV1(I)= ((RSR(I))*(AVGCR(I))*((S*DEMMAD(I))**2))/DEM(I)

          V(I)= (PLTFC(I)-PTAT(I))*(((S*DEMMAD(I))**2) + (RSR(I)**2)*
     C((S*CRMAD(I))**2)+(AVGCR(I)**2)*((S*RSRMAD(I))**2) +
     C((S*CRMAD(I))**2)*((S*RSRMAD(I))**2)) + (PTAT(I)*((S*DEMMAD(I))**2
     C))+ ((DEM(I)**2)*((S*NTTMAD(I))**2)) + ((DEM(I)-QREGEN(I))**2)*
     C(((S*PLTMAD(I))**2)+((S*NTTMAD(I))**2))

        OPTION(I)= (PLTFC(I)-PTAT(I))*(((S*DEMMAD(I))**2) + (RSR(I)**2)*
```

```
     C((S*CRMAD(I))**2)+(AVGCR(I)**2)*((S*RSRMAD(I))**2) - 2*COV1(I) +
     C((S*CRMAD(I))**2)*((S*RSRMAD(I))**2)) + (PTAT(I)*((S*DEMMAD(I))**2
     C))+ ((DEM(I)**2)*((S*NTTMAD(I))**2)) + ((DEM(I)-QREGEN(I))**2)*
     C(((S*PLTMAD(I))**2)+((S*NTTMAD(I))**2))

          PVAR(I)= (PLTFC(I)-PTAT(I))*(((S*DEMMAD(I))**2) + (RSR(I)**2)*
     C((S*CRMAD(I))**2)+(AVGCR(I)**2)*((S*RSRMAD(I))**2) - 2*COV(I) +
     C((S*CRMAD(I))**2)*((S*RSRMAD(I))**2)) + (PTAT(I)*((S*DEMMAD(I))**2
     C))+ ((QREGEN(I)**2)*((S*NTTMAD(I))**2)) + (((DEM(I)-QREGEN(I))**
     C2)*((S*PLTMAD(I))**2))

          PPV(I)=LTDEM(I)-LREGEN(I)+TREGEN(I)

*  DATA CHECK AND SCRUB FOR BAD OR ERRONEOUS DATA ELEMENTS

      IF(LTDEM(I).LE.0) THEN
           BDATA = BDATA + 1
           GO TO 10

      ELSE IF (PVAR(I).LT.0.OR.PPV(I).LT.0.OR.V(I).LT.0) THEN
           BDATA = BDATA + 1
           GO TO 10

      ELSE IF (V1(I).LT.0.OR.OPTION(I).LT.0) THEN
           BDATA = BDATA + 1
           GO TO 10

      END IF

      GDATA = GDATA + 1

* CALCULATE VARIANCE TO MEAN RATIOS
          RATIO1(I)=V1(I)/PPV(I)
          RATIO2(I)=PVAR(I)/PPV(I)
          RATIO3(I)=OPTION(I)/PPV(I)
          RATIO4(I)=V(I)/PPV(I)
          RATDEL(I) = RATIO1(I) - RATIO3(I)
          RATDIF(I) = RATIO1(I) - RATIO2(I)
          IF (RATDIF(I).LT.0.) THEN
               NEGDIF = NEGDIF + 1
          ELSE IF(RATDIF(I).GT.0.) THEN
               POSDIF = POSDIF + 1
          END IF

          IF (RATDEL(I).LT.0.) THEN
               NEGDEL = NEGDEL + 1
          ELSE IF(RATDEL(I).GT.0.) THEN
               POSDEL = POSDEL + 1
          END IF

      IF((V1(I)-V(I)).LT.0) THEN
           DEL=DEL+1
      END IF

* CALCULATE STANDARD DEVIATION
```

```
      V1SD(I)=V1(I)**.5
      PVARSD(I)=PVAR(I)**.5
      OPSD(I)=OPTION(I)**.5

*  REPORT WRITER AND DATA OUTPUT

*  DATA OUTPUT FOR IMPROVEMENT CALCULATION
      IF(PVAR(I).GT.V1(I).OR.OPTION(I).GT.PVAR(I)) THEN
          GO TO 100
      END IF
      DIFF(I)=PVARSD(I)-OPSD(I)
      DELTA(I)=(V1(I)**.5)-(PVAR(I)**.5)
      TOTDEL=TOTDEL + DELTA(I)
      NUM=NUM+1
      WRITE(3,95) I, DELTA(I),DIFF(I)
95    FORMAT('-',I5,2X,'DELTA = ',F10.3,2X,'DIFF = ',F10.3)
      IF(DIFF(I).LE.1) THEN
        ONEF=ONEF+1
      ELSE IF(DIFF(I).LE.2.AND.DIFF(I).GT.1) THEN
        TWOF=TWOF+1
      ELSE IF(DIFF(I).LE.3.AND.DIFF(I).GT.2) THEN
        THREEF=THREEF+1
      ELSE IF(DIFF(I).LE.5.AND.DIFF(I).GT.3) THEN
        FIVEF=FIVEF+1
      ELSE IF(DIFF(I).LE.10.AND.DIFF(I).GT.5) THEN
        TENF=TENF+1
      ELSE IF(DIFF(I).GT.10) THEN
        GTENF=GTENF+1
      END IF
      IF(DELTA(I).LE.1) THEN
        ONEL=ONEL+1
      ELSE IF(DELTA(I).LE.2.AND.DELTA(I).GT.1) THEN
        TWOL=TWOL+1
      ELSE IF(DELTA(I).LE.3.AND.DELTA(I).GT.2) THEN
        THREEL=THREEL+1
      ELSE IF(DELTA(I).LE.5.AND.DELTA(I).GT.3) THEN
        FIVEL=FIVEL+1
      ELSE IF(DELTA(I).LE.10.AND.DELTA(I).GT.5) THEN
        TENL=TENL+1
      ELSE IF(DELTA(I).GT.10) THEN
        GTENL=GTENL+1
      END IF

* SPLIT DATA INTO LLOW,  MLOW, HLOW, MED AND HIGH DEM ITEMS FOR ANALYSIS

100   IF (DEM(I).LT.1) THEN
         GO TO 114
      ELSE IF (DEM(I).LT.2.AND.DEM(I).GE.1) THEN
         GO TO 154
      ELSE IF (DEM(I).LT.5.AND.DEM(I).GE.2) THEN
         GO TO 164
      ELSE IF (DEM(I).LT.20.AND.DEM(I).GE.5) THEN
         GO TO 124
      ELSE IF (DEM(I).GE.20) THEN
         GO TO 134
      END IF
```

```
*LOW LOW DEMAND OUTPUT

114       IF (RATDIF(I).LT.0.) THEN
               NDIF1 = NDIF1 + 1
          ELSE IF(RATDIF(I).GE.0.) THEN
               PDIF1 = PDIF1 + 1
          END IF

          IF (RATDEL(I).LT.0.) THEN
               NDEL1 = NDEL1 + 1
          ELSE IF(RATDEL(I).GE.0.) THEN
               PDEL1 = PDEL1 + 1
          END IF

          IF(RATIO4(I).GE.P) THEN
               COUNT1 = COUNT1 + 1
          END IF

      WRITE(10,115) I, V1(I), PVAR(I), OPTION(I), V(I), PPV(I),
     CDIFF(I),V1SD(I), PVARSD(I), OPSD(I), RATIO4(I)
115   FORMAT ('-',I5,9(F10.3),F10.3)
         GO TO 10

*MED LOW DEMAND FILE OUTPUT

154       IF (RATDIF(I).LT.0.) THEN
               NDIF2 = NDIF2 + 1
          ELSE IF(RATDIF(I).GE.0.) THEN
               PDIF2 = PDIF2 + 1
          END IF

          IF (RATDEL(I).LT.0.) THEN
               NDEL2 = NDEL2 + 1
          ELSE IF(RATDEL(I).GE.0.) THEN
               PDEL2 = PDEL2 + 1
          END IF

          IF(RATIO4(I).GE.P) THEN
               COUNT2 = COUNT2 + 1
          END IF

      WRITE(11,155) I, V1(I), PVAR(I), OPTION(I), V(I), PPV(I),
     CDIFF(I),V1SD(I), PVARSD(I), OPSD(I), RATIO4(I)
155   FORMAT ('-',I5,9(F10.3),F10.3)

         GO TO 10

*HIGH LOW DEMAND OUTPUT

164       IF (RATDIF(I).LT.0.) THEN
               NDIF3 = NDIF3 + 1
          ELSE IF(RATDIF(I).GE.0.) THEN
               PDIF3 = PDIF3 + 1
          END IF
```

```
          IF (RATDEL(I).LT.0.) THEN
               NDEL3 = NDEL3 + 1
          ELSE IF(RATDEL(I).GE.0.) THEN
               PDEL3 = PDEL3 + 1
          END IF

          IF(RATIO4(I).GE.P) THEN
               COUNT3 = COUNT3 + 1
          END IF

      WRITE(7,165) I, V1(I), PVAR(I), OPTION(I), V(I), PPV(I),
     CDIFF(I),V1SD(I), PVARSD(I), OPSD(I), RATIO4(I)
165   FORMAT ('-',I5,9(F10.3),F10.3)

         GO TO 10

*MED DEMAND OUTPUT

124       IF (RATDIF(I).LT.0.) THEN
               NDIF4 = NDIF4 + 1
          ELSE IF(RATDIF(I).GE.0.) THEN
               PDIF4 = PDIF4 + 1
          END IF

          IF (RATDEL(I).LT.0.) THEN
               NDEL4 = NDEL4 + 1
          ELSE IF(RATDEL(I).GE.0.) THEN
               PDEL4 = PDEL4 + 1
          END IF

          IF(RATIO4(I).GE.P) THEN
               COUNT4 = COUNT4 + 1
          END IF

      WRITE(8,125) I, V1(I), PVAR(I), OPTION(I), V(I), PPV(I),
     CDIFF(I),V1SD(I), PVARSD(I), OPSD(I), RATIO4(I)
125   FORMAT ('-',I5,9(F10.3),F10.3)

         GO TO 10

*HIGH DEMAND OUTPUT

134       IF (RATDIF(I).LT.0.) THEN
               NDIF5 = NDIF5 + 1
          ELSE IF(RATDIF(I).GE.0.) THEN
               PDIF5 = PDIF5 + 1
          END IF

          IF (RATDEL(I).LT.0.) THEN
               NDEL5 = NDEL5 + 1
          ELSE IF(RATDEL(I).GT.0.) THEN
               PDEL5 = PDEL5 + 1
          END IF

          IF(RATIO4(I).GE.P) THEN
               COUNT5 = COUNT5 + 1
```

```
        END IF

      WRITE(9,135) I, V1(I), PVAR(I), OPTION(I), V(I), PPV(I),
     CDIFF(I),V1SD(I), PVARSD(I), OPSD(I),RATIO4(I)
135   FORMAT ('-',I5,9(F10.3),F10.3)

10    CONTINUE

      UNCHNG = I - (POSDIF + NEGDIF)
      UNDEL = I - (POSDEL + NEGDEL)

*TOTAL SUMMARY DATA OUTPUT

      WRITE (3,145) BDATA, GDATA, NEGDIF, POSDIF, UNCHNG, NEGDEL, POSDEL
     C, UNDEL, TOTDEL, NUM, DEL
145   FORMAT ('-'/'0 BDATA = ',I5/'0 GDATA = ',I5/'ONEGDIF = ',I5/
     C'OPOSDIF = ',I5/'OTOTAL VARIANCE UNCHANGED = ',I5/'ONEGDEL = ',
     CI5/'OPOSDEL = ',I5/'OTOTAL VARIANCE UNCHANGED = ',I5/
     C'OTOTAL DELTA OF S.D. = ',F10.3/'ONUMBER OF ITEMS = ',I5/
     C'ONUMBER OF ITEMS WHEN V<V1 = ',F10.3)

      WRITE(3,300) ONEF,TWOF,THREEF,FIVEF,TENF,GTEN,ONEL,TWOL,THREEL,
     CFIVEL,TENL,GTENL
300   FORMAT ('-'/ 12(I5))
*SUMMARY DATA OUTPUT BY DEMAND

      WRITE (3,215)  NDIF1, PDIF1, NDEL1, PDEL1, COUNT1
      WRITE (10,215)  NDIF1, PDIF1, NDEL1, PDEL1, COUNT1
215   FORMAT ('-'/'OLOW DEMAND SAMPLES'/'ONDIF1 = ',I5/'OPDIF1 = ',I5/
     C'ONDEL1 = ',I5/'OPDEL1 = ',I5/'OCOUNT1 = ',I5)

      WRITE (3,255)  NDIF2, PDIF2, NDEL2, PDEL2, COUNT2
      WRITE (11,255)  NDIF2, PDIF2, NDEL2, PDEL2, COUNT2
255   FORMAT ('-'/'OMED LOW DEMAND SAMPLE'/'ONDIF2 = ',I5/'OPDIF2 = ',I5
     C/'ONDEL2 = ',I5/'OPDEL2 = ',I5/'OCOUNT2 = ',I5)

      WRITE (3,265)  NDIF3, PDIF3, NDEL3, PDEL3,COUNT3
      WRITE (7,265)  NDIF3, PDIF3, NDEL3, PDEL3, COUNT3
265   FORMAT ('-'/'OHIGH LOW DEM SAMPLES'/'ONDIF3 = ',I5/'OPDIF3 = ',I5/
     C'ONDEL3 = ',I5/'OPDEL3 = ',I5/'OCOUNT3 = ',I5)

      WRITE (3,225)  NDIF4, PDIF4, NDEL4, PDEL4, COUNT4
      WRITE (8,225)  NDIF4, PDIF4, NDEL4, PDEL4,COUNT4
225   FORMAT ('-'/'OMEDIUM DEMAND SAMPLES'/'ONDIF4 = ',I5/'OPDIF4 = ',I5
     C/'ONDEL4 = ',I5/'OPDEL4 = ',I5/'OCOUNT4 = ',I5)

      WRITE (3,235)  NDIF5, PDIF5, NDEL5, PDEL5, COUNT5
      WRITE (9,235)  NDIF5, PDIF5, NDEL5, PDEL5, COUNT5
235   FORMAT ('-'/'OHIGH DEMAND SAMPLES'/'ONDIF5 = ',I5/'OPDIF5 = ',I5/
     C'ONDEL5 = ',I5/'OPDEL5 = ',I5/'OCOUNT5 = ',I5)

      STOP
      END
```

APPENDIX C

DETAILED OUTPUT LISTING

I	- Item Number
V1	- Variance on File
PVAR	- Variance calculated by PVAR
OPTION	- Variance calculated by OPTION
V	- Variance calculated by UICP formula
Z	- Mean net leadtime demand (PPV)
Δ sd	- difference in between PVAR standard deviation and OPTION standard deviation (PVAR s.d. - OPTION s.d.)
V1 sd	- Square Root of V1 (standard deviation)
PVAR sd	- Square Root of PVAR (standard deviation)
OPTION sd	- Square Root of OPTION (standard deviation)
V/Z	- Variance to Mean ratio

I	V1	PVAR	OPTION	V	Z	Δ SD	V1SD	PVAR SD	OPTION SD	V/Z
36	5023.379	1482.285	254.502	1482.285	105.620	22.547	70.876	38.500	15.953	14.034
97	13199.719	18595.754	2413.862	18595.754	193.650	0.000	114.890	136.366	49.131	96.028
113	5271.066	2987.308	274.486	3106.028	64.920	38.089	72.602	54.656	16.568	47.844
241	2942.332	650.905	465.541	650.905	71.250	3.936	54.243	25.513	21.576	9.135
290	4100.773	2518.112	566.498	2589.786	51.450	26.380	64.037	50.181	23.801	50.336
292	6695.910	1497.289	728.498	1497.289	123.220	11.704	81.829	38.695	26.991	12.151
313	2671.482	5747.102	1876.886	5747.102	96.750	0.000	51.686	75.810	43.323	59.402
387	24102.812	11455.176	2607.945	11455.176	188.350	55.961	155.251	107.029	51.068	60.819
560	4824.566	15793.531	2578.528	15793.531	99.080	0.000	69.459	125.672	50.779	159.402
879	3696.021	3292.999	926.283	3310.759	82.890	26.950	60.795	57.385	30.435	39.942
912	2784.769	12249.891	1604.281	17351.262	68.710	0.000	52.771	110.679	40.053	179.760
1123	82512.937	59759.992	19812.965	67521.062	369.510	103.700	287.251	244.458	140.759	182.731
1286	11429.637	23712.074	2579.768	22867.633	175.910	0.000	106.910	153.987	50.791	129.996
1287	4472.211	15911.398	1713.472	15922.937	93.430	0.000	66.500	126.140	41.394	170.476
1341	26373.969	3408.350	2626.092	3497.810	306.980	7.136	162.401	58.381	51.245	11.394
1365	7726.949	17683.113	1952.088	21491.113	135.630	0.000	87.903	132.978	44.182	158.454
1366	19959.168	80109.125	38789.055	99976.000	254.930	0.000	141.277	283.036	196.949	392.170
1370	87616.500	231444.875	3624.648	269876.062	729.660	0.000	296.001	481.087	60.205	369.865
1646	592673.500	467730.000	467309.250	467730.000	6558.996	0.308	769.853	683.908	683.600	71.311
1663	4712.086	12041.215	2381.762	12041.215	97.520	0.000	68.645	109.737	48.803	123.474
1730	15199.637	22313.551	4779.898	22313.551	212.720	0.000	123.287	149.377	69.137	104.896
1791	3207.094	1352.951	373.564	1448.951	60.460	17.455	56.631	36.782	19.328	23.965
1890	15284.000	2287.788	587.166	2326.068	169.690	23.599	123.628	47.831	24.232	13.708
1891	35834.844	30795.516	17455.398	37147.898	438.280	43.368	189.301	175.487	132.119	84.758
1959	5019.367	4016.417	375.707	4163.137	65.600	43.992	70.847	63.375	19.383	63.462
2320	10893.074	4364.207	1129.218	4364.207	191.110	32.458	104.370	66.062	33.604	22.836

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